International Journal of Agricultural
Science and Research (IJASR)
ISSN(P): 2250-0057; ISSN(E): 2321-0087
Vol. 5, Issue 6, Dec 2015, 169-176

DRYING KINETICS OF MICROWAVE PRE-TREATED TRAY DRYING OF TOMATO

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ABSTRACT

This study was conducted to evaluate the drying kinetics of microwave pre-treated tomato slices. Microwave power levels 750 W, 1000 W and 1250 W and exposure time at 10, 20 and 30 min were considered as process variables. The thickness of the tomato slices was taken as 5 mm and tray dryer temperature was maintained at 60 °C. Drying kinetics study showed that drying curve followed a falling rate period throughout the process of drying. There was 45-50% reduction in the drying time for the slowest and the fastest experimental process compare to the control method. The Two-Term model was appropriate to predicting the moisture ratio with high R^2 and low RMSE value, 0.997, 0.0121, respectively. The moisture diffusivity and activation energy was 1.97×10-6 m2/s and 44.99 kJ / mol respectively.

***KEYWORDS:** Microwave, Tray Drying, Two-Term Model, Activation Energy, Moisture Diffusivity*

Received: Oct 19, 2015; **Accepted:** Oct 26, 2015; **Published:** Nov 07, 2015; **Paper Id.:** IJASRDEC201523

Original Article

INTRODUCTION

Tomato (*Solanum lycopersicum*) is the world's most commonly commercially produced vegetable (Jumah et al., 2004). It is utilized in the manufacture of various products, such as juice, puree, paste, ketchup, sauce and soups (Kramer and Kwee, 1977; Al-Wandawi et al., 1985). India is the second largest producer of fruits (81.28 million tonnes) and vegetables (162.18 million tonnes) in the world, contributing 10.28% and 17.07% of total world production respectively (FAOSTAT, 2013). A significant qualitative and quantitative loss occurs in the produce from harvest till consumption. Processing plays an important role in conservation and effective utilization of these perishable commodities. However, only less than 2-3% of total production of fruits and vegetables processed (Avantina Sharma, 2006) in India. In India, major tomato producing states are Andhra Pradesh, Karnataka, Madhya Pradesh, Odisha, Gujarat, Bihar, West Bengal, Maharashtra, Chhattisgarh and Himachal Pradesh (NHB, 2014).

The demand of tomato in the country is increasing day-by-day, with the increasing population and its preference for tomato. The objective in drying agricultural products is the reduction of the moisture content to a level, which allows safe storage over an extended period. Also, it brings about substantial reduction in mass and volume, minimising packaging, storage and transportation costs (Okos et al., 1992).

Food industry is now a major user of microwave energy, especially in the drying of vegetables and post-baking of biscuits. Principle of microwave heating and drying can greatly reduce the drying time of the biological products without quality degradation (Vadivambal and Jayas, 2007). The penetrating quality of electromagnetic waves and distribution leading to uniform heating, selective absorption by water, which leads to a uniform

moisture profile within the material. Ease of control due to rapid, volumetric heating response, microwaves and convection heating may be applied simultaneously or at different times. It has been proven that combination drying is an effective way, particularly when microwaves are introduced in drying to reduce the moisture below 20% (Mudgett et al., 1986). It is unique in the way that microwaves don't require a heat transfer medium and generate heat with in the food itself very rapidly with little dependence on conductance. Microwave has a wide application in the food industry including pasteurization, sterilization, blanching, cooking, drying and thawing. Its use at domestic level has also become common with the change in lifestyles and consumer's attitude towards ready to eat foods.

MATERIALS AND METHODS

COLCRCH- 3, a popular variety grown in Tamil Nadu was chosen for the studies. Samples were procured from a local market in Thanjavur (Tamil Nadu). Only ripe uniform size fruits were selected and over-riped and flush fruits were removed by picking. Fresh samples were sorted visually based on colour and size (average diameter and weight were 6± 0.2 cm, 75 ± 5g respectively). Fresh samples were purchased from the market daily. Tomatoes were smooth round to slightly oblong, medium sized, ripe fruits bright red coloured. A domestic slicer (Essae-Teraoka Ltd, Model: IND/09/10/490) was used to slice and the slicer has a detachable knife to facilitate cutting of the tomato into appropriate thickness.

Microwave dryer (Enerzi microwave system, model No- PTF-2515) was used for drying experiments. The dryer consists of two heaters, and blowers as well as two magnetrons for drying the sample; a conveyer belt was attached with the machine for continuous drying of the product. A control panel is available for controlling the parameters like belt speed, microwave power level, heater temperature, etc.

After microwave treatment, drying experiments were performed in a laboratory scale tray dryer (Industrial and laboratory tool corporation. P.B No. 6063). Tomato slices were spread on perforated trays made of stainless steel. The pre-treated tomato samples were placed on the tray in a single layer, maintaining a temperature of about 60 ± 2 °C and air velocity of 1.5 ± 2 m/s.

Drying Kinetics

Moisture content was determined according to AOAC (1984) method. Ten gram of samples was accurately weighed in moisture boxes and placed in a hot air oven (Everflow Scientific Instruments) at 105±2°C for 3 h. After drying, the samples were removed from the oven and placed in desiccators to cool for about 30 minutes and then weighed.

Moisture ratio was calculated by $MR = \frac{M-M_e}{M_0-M_e}$ (1)

where, M is the instantaneous moisture content, M_e is the equilibrium moisture content, and M_0 is the initial moisture content (% db).

Drying Rate, R in grams of water removed per minute per 100 grams of bone dry matter is expressed as:

$$R = \frac{Amount\ of\ moisture\ removed}{Time\ taken * \left(\frac{Total\ bone\ dry\ weight\ of\ sample\ removed\ in\ gram}{100}\right)} \quad (2)$$

The drying curves were plotted with drying rate versus drying time and moisture ratio versus drying time.

Drying Models

Among the treatments, the best combination was taken and fitted in different models as shown in Table 1. For the purpose of design and to describe the drying kinetics, a common way is to predict the mathematical models into the experimental data. Mathematical model was applied to predict the drying characteristics. The models tried are shown in table.

Table 1: Models used for Predicting the Moisture Ratio

Sl No	Model Equation	Name	References
1	MR=a exp(-kt)	Henderson and Pebis	Henderson and Pebis(1961)
2	MR=a exp(-$k_0t) + bexp(k_1t)$	Two – term	Henderson(1974)
3	MR=1+at+bt^2	Wang and Singh	Wang and Singh(1978)
4	MR=b/(1+a exp(kt))	Logistic	Chandra and Singh(1995)
5	MR=a exp(-kt)+c	Logarithmic	Togrul and Pehlivan(2002)
6	MR= a exp(-kt)+b exp(-gt)+c exp(-ht)	Modified Henderson and Pebis	McMinn(2006)
7	MR=a exp(-c($\frac{t}{L^2}$))	Simplified Fick's diffusion	Diamante and Munro(1991)

Moisture Diffusivity

Moisture diffusion coefficients were typically determined by plotting experimental drying data in terms of ln $\left[\frac{M}{M_0}\right]$ versus drying time by square of the thickness of the slices $\left[\frac{t}{L^2}\right]$, here t is the drying time (min), and L is the thickness of the tomato slices (mm). The slope of the curve is a measure of the effective diffusivity.

Fick's second law equation of diffusion was used to calculate the effective diffusivity, considering a constant moisture diffusivity, infinite slab geometry and uniform initial moisture distribution (Crank, 1975)

$$(MR) = \left[\frac{8}{\pi^2}\right] exp\left[-\frac{\pi^2 D_{eff}}{L^2}\ t\right] \tag{3}$$

Alzamora et al. (1980) calculated moisture diffusion coefficients by plotting experimental drying data in terms of ln $\left[\frac{M}{M_0}\right]$ versus drying time by thickness of the slices$\left[\frac{t}{L^2}\right]$. The slope of line gave effective diffusivity.

Activation Energy

The least amount of energy required to activate atoms or molecules to a state in which they can undergo a chemical reaction. Activation energy can be calculated by using effective diffusivity and Arrhenius dependence. The pre-exponential term, A in the Arrhenius equation, has been ignored because it is not directly involved in relating temperature and activation energy, which is the main practical use of the equation. (Svante Arrhenius, 1889). Doymaz (2007) used same equation for finding out the activation energy of okra.

$$k = A\ e^{-Ea\,/\,RT} \tag{4}$$

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{R\,T}\right] \tag{5}$$

where

Ea is the activation energy (kJ/mol)

A and D_0 are the pre exponential factor of Arrhenius equation (m^2/s)

k is the rate coefficient,

T is the temperature of air (K)

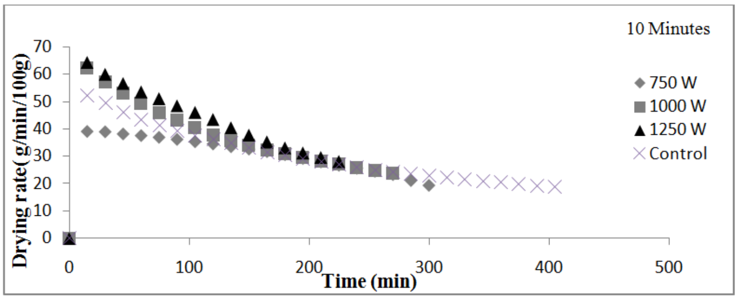
R is the universal gas constant (kJ/mol.K).

RESULTS AND DISCUSSIONS

The results obtained from the experimental work and the information drawn from them. The effect of duration of microwave pre-treatment and combined effect of tray drying on the drying time, Moisture content, Moisture ratio, and drying rate. And also it shows the moisture diffusivity and activation energy. During the drying of tomato slices of 5mm thickness (500±2 g) at three power level microwave pre-treated, tray dried sample, reduction in moisture content from 91±0.5% (wb) to 10±0.5 %(wb) was observed. The drying process took nearly 270 to 345 min, 220 to 240 min and 190 to 230 min of 30 to 10 min exposure time at 750, 1000 and 1250 W respectively. The control sample took 430 min of drying time, kept at 60^0 C. As the microwave power and exposure time increased the drying time of tomato slices was reduced ($P<0.05$). Power levels used for the pre-treatment had a significant effect on the drying time. The difference in drying time may be due to the difference in drying rate. Microwave drying greatly reduced the drying time of tomato slices compared to hot air drying alone as reported by (Demiray et al., 2013).

Drying rate was calculated as a quantity of moisture removed per unit time per 100g dry mass [g/min/100g]. Drying rate curves for tomato slices dried at different microwave power level and exposure time are given in Figure 1. Depending on the microwave pre-treatment, drying rate of tomato slices increased then slowly decreased when the time increased. The initial drying rate increased with an increase in microwave power level from 750 to 1250 W and exposure time from 10 to 30 min. A constant rate period was not observed in the microwave drying of tomato slices; the curves of drying process presented a typical falling rate period with the exception of a very short accelerated period at the start. The drying rate of tomato slices was faster at the starting phase than the following phase. This observation is an agreement with previous reports on drying of biological products by Diamante and Munro (1991) and Doymaz and Pala (2003). But in the control sample there was not much quick falling rate and there was an obvious inflection point in the drying rate curves.

The moisture ratios versus time for the microwave pre-treatment at different power levels and without pre-treatments are shown in the Figure 2. The total drying time taken to reach the final moisture content (10%) for different power level samples were 345 to 210 min at 750 to 1250 W, with respect to exposure time 10 to 30 min respectively. And without microwave pre-treated sample it was nearly 405 min. Obviously within a certain microwave range (750-1250 W in this study) increasing output power speeds up the drying process, thus shortening the drying time. This result is similar to the results of drying of apple slices (Ramaswamy and Nieuwenhuijzen, 2002; Bai, et al., 2002).



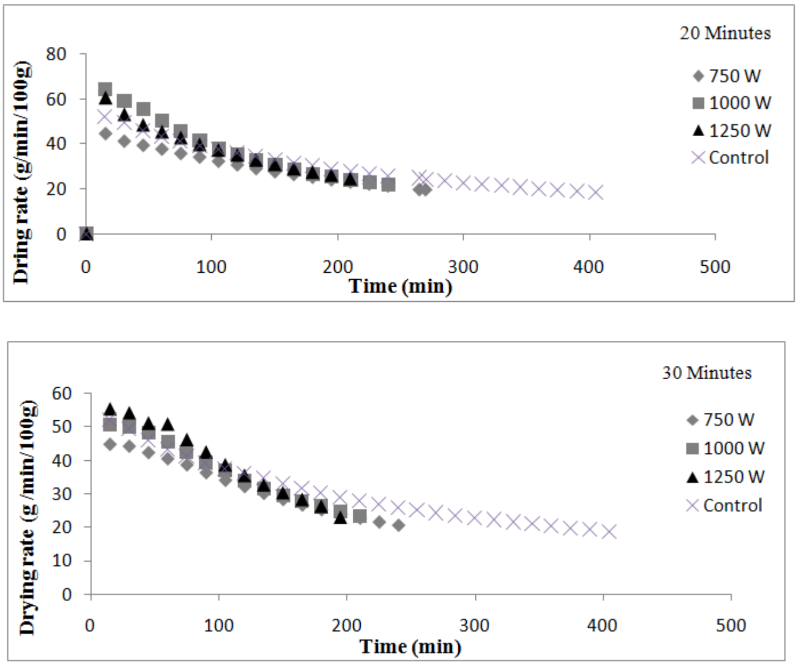


Figure 1: Effect of Drying Time and Microwave Pre-Treatment on Drying Rate of Tomato Slices

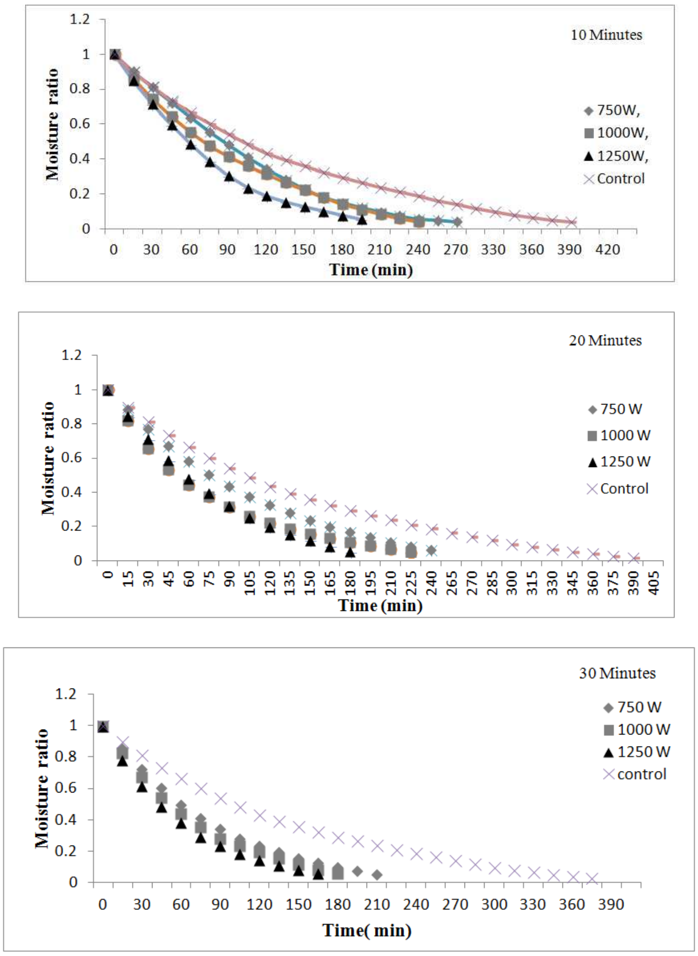


Figure 2: Effect of Drying Time and Microwave Pre-Treatment on Moisture Ratio of Tomato Slices

Heat is generated when microwave interacts with the polar water molecules in fruits and vegetables and significantly high drying rate was achieved when compared to air drying alone (Schiffmann, 1995). Heating was immediate due to radioactive energy transfer; hence the surface to centre conduction stage is largely eliminated due to gradual vapour pressure difference. During hot air drying, moisture was initially evaporated from the surface while the inner core water diffuses to the surface slowly.

Moisture removal at first half of drying was found to be high in all the treatments. This must be because of the high moisture content of the samples, which observed more microwave energy. The sample treated with high moisture level and high exposure time had more moisture removal rate and hence they dried more rapidly than the control. It took 255, 240, and 210 min to reach moisture ratio nearly 0.05 at microwave power output level 750 W, at 10, 20 and 30 min exposure time respectively. And 240, 225, and 195 min to reach same moisture ratio at microwave output level 1000 W, at 10, 20 and 30 min exposure time respectively. And 195,180 and 165 min to reach same moisture ratio at microwave output level 1250 W, at 10, 20 and 30 min exposure time respectively.

Effective Moisture Diffusivity

The falling rate period of drying depends upon the movement of moisture within the material from the centre to surface and the removal of moisture from the surface of the product. Since it was accepted that the movement of moisture takes place by liquid or vapour diffusion, the diffusivity coefficient (D_{eff}) was found out by assuming the shape of the tomato slices as a thin slab. This assumption was made in accordance with Giovananelli et al., (2002) in modelling of moisture movement in tomato slices, where they concluded that models assuming thin slab would predict higher moisture diffusivity.

By using Design Expert software, it was found that the optimised microwave treatment combination based on desirability value (0.66) was W_2t_2 (1000 W, 20 min). The corresponding values were fitted in mathematical models for this drying combination.

The diffusivity coefficient was found out for optimised microwave pre-treated combination (1000 W and 20 min microwave exposure time) and the coefficient of diffusivity was 1.97×10^{-6} m^2/s. Moisture diffusion coefficient was determined by plotting experimental drying data in terms of $\ln\left[\frac{M}{M_0}\right]$ versus drying time by square of thickness of the slices$\left[\frac{t}{L^2}\right]$, shown in Figure 3. The slope of the curve is a measure of the effective diffusivity. Hawlader et al. (1991) showed similar behaviour.

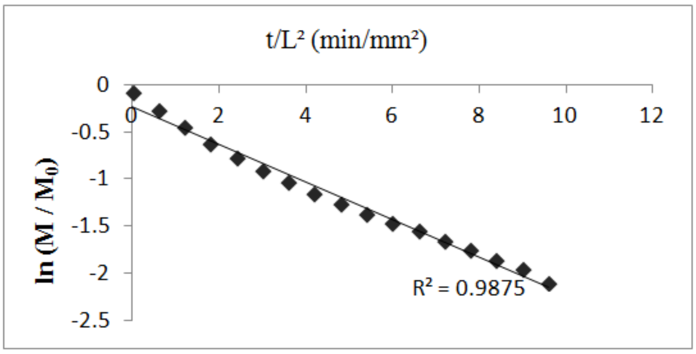


Figure 3: Plot of Ln$(M|M_0)$ Vs $(t|L^2)$

Mathematical Modelling

Simple type of drying models assumes that rate of exchange in moisture content is proportional to the difference between moisture content and equilibrium moisture content (EMC) of the material. The experimental data of observed values versus predicted values by Two-term and Logistic model are presented in Figure 4. The closeness of the experimental observed values plotted against predicted values shows the effectiveness of the predictive capacity of the optimised treatment combination. And considering a highest R^2 value 0.997 and 0.989, lowest RSME values 0.012 and 0.0113 both Two-term and Logistic model were best fitted.

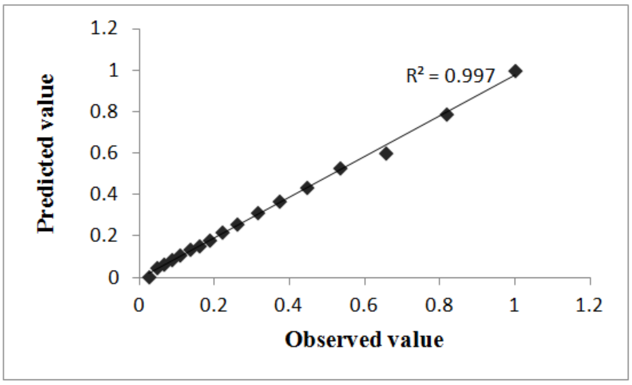


Figure 4: Observed Vs. Predicted Moisture Ratio in Two-Term Model

CONCLUSIONS

The effect of microwave power level and exposure time on drying kinetics of tomato slices was studied. The drying time reduces with increasing power level and exposure time. The drying time reduces from 270 min to 210 min. Based on physic-chemical analysis optimised treatment combination was decided. The results obtained where optimised for the desirable properties of high lycopene content, high beta carotene content, low colour value, high rehydration ratio and high total soluble solid for identifying the best treatment combination by using Design expert 6.0.8 software. From the analysis it was found that the treatment combination W_2T_2 (1000 W and 20 min exposure time) was superior to other treatments from the study, we can conclude that tomato slices can be pre-treated with microwave power (1000 W) and exposure time 20 min and dried at 60°C in tray dryer to get a tomato powder of acceptable quality which can be used in food preparation like sauce, ketchup, juice, thickening agent etc.

REFERENCES

1. *Al-Wandawi, H., Abdul-Rahman, M. and Al-Shaikhly, K. (1985). Tomato processing wastes as essential raw materials source. Journal of Agricultural and Food Chemistry, 33(5), 804-807.*
2. *Alzamora., Gomez, R., Vidales, S. and Alzamora, S. M., (1980). Diffusion in banana drying. Journal of Food Engineering, 7(4), 219-26.*
3. *Avantina Sharma.(2006). Text book of food science and technology, First edition, Publication-International Book Distribution Corporation Lucknow.285, 14-19.*
4. *AOAC, (1984). Moisture content in perishable vegetables. Official methods of analysis. 2nd edition, 65-81.Association of Official Analytical Chemists Press, Washington, DC, USA.*
5. *Crank, J. (1975). The mathematics of diffusion. 2 nd edition. New York, Editorial Oxford university press.*

6. *Demiray, E., Tulek, Y. and Yilmaz, Y. (2013). Degradation kinetics of lycopene, β-carotene and ascorbic acid in tomatoes during hot air drying. LWT-Food Science and Technology, 50(1), 172-176.*
7. *Diamante, L. M. and Munro, P. A. (1991). Mathematical modelling of hot air drying of sweet potato slices. International Journal of Food Science and Technology, 26(1), 99-109.*
8. *Doymaz, I. (2007). Air-drying characteristics of tomatoes. Journal of Food Engineering, 78(4), 1291-1297*
9. *Doymaz, I. and Pala, M. (2003). The thin-layer drying characteristics of corn. Journal of Food Engineering, 60(2), 125-130.*
10. *Giovanelli, G., Zanoni, B., Lavelli, V. and Nani, R. (2002). Water sorption, drying and antioxidant properties of dried tomato products. Journal of Food Engineering, 52(2), 135-141.*
11. *Hawlader, M. N. A., Uddin, M. S., Ho, J. C., and Teng, A. B. W. (1991). Drying characteristics of tomatoes. Journal of Food Engineering, 14(4), 259-268.*
12. *Indian horticulture database, 2013. National Horticulture Board, Ministry of Agriculture, Government of India, 2014.*
13. *Jumah, R., Banat, F., Al-Asheh, S. and Hammad, S. (2004). Drying kinetics of tomato paste. International Journal of Food Properties, 7, 253–259.*
14. *Kramer, A. and Kwee, W. H. (1977). Functional and nutritional properties of tomato protein concentrate. Journal of Food Science and Technology. 42 (1), 207–211.*
15. *Mudgett, R.E., Rao, M.A., and Rizvi, S.S.H (1986). Electrical properties of foods. A review of basic principles, Journal of Food Engineering, 8, 389-457.*
16. *Okos, M. R., Narsimhan, G., Singh, R. K. and Witnauer, A. C. (1992). Food dehydration. Handbook of Food Engineering, 3, 23-45.*
17. *Ramaswamy, H. S. and Van Nieuwenhuijzen, N. H. (2002). Evaluation and modeling of two-stage osmo-convective drying of apple slices. Drying Technology, 20(3), 651-667.*
18. *Schiffmann, R. F. (1995). Microwave and dielectric drying,. Handbook of Industrial Drying, Second Edition, CRC Press, 1, 345-372*
19. *Svante Arrhenius (1889). Hydrogen diffusion in synthetic Fe-free diopside. European Journal of Mineralogy, 21(5), 963-970.*
20. *Vadivambal, R. and Jayas, D.S (2007). Changes in quality of microwave treated agricultural products-a review. Biosystems Engineering, 98(4), 1-16.*
21. *Retrieved from http://faostat.fao.org/site/567/desktopdefault.aspx#ancor*